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Piotr Sugier; Maria Curie-Skłodowska University in Lublin, Poland; https://orcid.org/0000-0002-1448-1517

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ORIGINAL RESEARCH PAPER in HERBOLOGY

Occurrence of Weeds in an Orchard due to Cultivation of Long-Term Perennial Living Mulches

Maria Licznar-Małańczuk*
Department of Horticulture, Wrocław University of Environmental and Life Sciences, Poland

*To whom correspondence should be addressed. Email: maria.licznar-malanczuk@upwr.edu.pl

Abstract
The living mulch permanence along with the succession of their weed infestation in an apple orchard were evaluated at the Research Station, Wrocław University of Environmental and Life Sciences. The perennial cover crops: white clover and colonial bent grass, as well as the annual dwarf nasturtium, were sown as living mulches in apple tree rows, in the year of establishing the orchard. Blue fescue was sown one year later to replace the dwarf nasturtium. The percent of covers and temporal dominance dynamics of weeds were estimated during the first 13 years of the orchard maintenance. The occurrence of annual weeds, which had been abundant in all the living mulches in the year of their sowing, decreased in the following years of orchard maintenance. Conversely, the dominance of several perennial weed species increased as the orchard reached the full cropping period. White clover exhibited the lowest permanence. Dynamic spreading of *Elymus repens* (L.) Gould and other species from the Poaceae family was the direct cause of this cover crop disappearance. The presence of perennial dicotyledonous weeds, primarily *Taraxacum officinale* Web. and *Convolvulus arvensis* L., also contributed to the diminished sod of all the living mulches. Blue fescue maintained satisfactory dominance relative to colonial bent grass for nearly the entire first decade of the research. Nevertheless, both grass living mulches were present on less than half of the tree row soil surface area, in the thirteenth year after planting of the apple trees.

Keywords
cover crop; fescue; colonial bent; clover; apple tree

1. Introduction

The weed ground cover and number of species in orchards are largely influenced by different soil management techniques (Cucci et al., 2016; Lisek, 2012; Mas et al., 2007). Prevention of weed infestation is conditional on proper crop management (Kropff & Walter, 2000). In orchards, herbicide application is the most commonly used method to maintain weed-free soil under the fruit tree canopy, but the drive alleys are grassed (Lisek, 2014). The urgent need to reduce excessive agrichemical use in an orchard motivates the pursuit of alternative means of weed control in the tree rows. An herbicide fallow can be replaced by cover crops. A different plant or a mix of species are established in tree row strips to occupy a vacant niche that weeds are trying to fill (Granatstein & Sánchez, 2009). A living mulch is a viable solution if its biomass prevails over the biomass of weeds (Linares et al., 2008). Insufficient initial growth and establishment of cover crops (Hogue et al., 2010) as well as inadequate living mulch cover (Hartley et al., 2000) create conditions for weed occurrence in a young orchard.

Annual weeds have different patterns of spread on a spatiotemporal scale. Regardless of their dispersal strategy, annual weeds require free space for seed germination and development (Wallinga et al., 2002; Wang et al., 2003). Optimal water conditions foster the growth of their populations (Andersen

et al., 2013; Shem-Tov & Fennimore, 2003). Annual weeds emerge in the year of cover crop sowing but become suppressed by living mulch cover (Licznar-Małańczuk, 2014, 2015; Tran et al., 2018). Perennial weeds, particularly dicotyledonous ones (Tworkoski & Glenn, 2012), gain prevalence by the time the living mulch is established (Licznar-Małańczuk, 2014, 2015). Mulching of the soil surface can prevent germination of weed seeds but is not effective against established perennial weeds (Bond & Grundy, 2001). The lack of soil tillage over many years favors the development and compensation of perennial plants (Lisek, 2012). The weed species richness in tree rows is lower for orchard floor management based on mown cover crops than for herbicide fallow or tillage (Tursun et al., 2018).

Cover crop may contribute to weed management by suppressing weed biomass, seed production and growth of rhizomes (Teasdale et al., 2007). Fabaceae plants can be employed as living mulches (den Hollander et al., 2007a, 2007b; Ross et al., 2001). The available literature concerning plant species used as living mulches in fruit cultivation covers primarily *Trifolium*, *Medicago*, and *Vicia*; followed by perennial grasses, especially *Festuca*, *Lolium*, and *Poa* (Licznar-Małańczuk, 2012). The evaluations of weed suppression capabilities exhibited by various living mulches do not extend beyond the initial years following tree planting (Andersen et al., 2013; Belding et al., 2004; Lipecki & Janisz, 2001), with the longest studies conducted over 5–7 years (Hogue et al., 2010; Licznar-Małańczuk, 2014). Likewise, research undertaken in older orchards, at the full cropping period, continue at most for four vegetation periods (Grantastein & Mullinix, 2008; Tworkoski & Glenn, 2012). These experiments do not show the full picture regarding the suitability of cover crops to orchards, which need to be maintained for 15–20 or more years. The aim of this study was to estimate the diversity of the most important weed species occurring in three living mulches: white clover (*Trifolium repens* L.), colonial bent grass (*Agrostis vulgaris* With.), and blue fescue (*Festuca ovina* L.) in apple tree rows. The examination lasted 13 years, focusing on percent of covers, as well as temporal dominance dynamics of the most important weeds.

2. Material and Methods

The field experiment was established on haplic luvisol derived from silty light loam at the Fruit Experimental Station in Samotwór (51°06′12″ N, 16°49′52″ E), which belongs to the Wrocław University of Environmental and Life Sciences. Apple trees (*Malus domestica* Borkh.) of the 'Ligol' cultivar on three rootstocks: P 22 (super-dwarf), P 16 (dwarf), and P 2 (semi-dwarf) were planted in spring 2004 (2,380 trees ha^{-1}). In spring 2004, after tree planting, three cover crops, used as living mulches in the apple orchard, were sown: white clover (*Trifolium repens*) of the 'Sonja' cultivar (10 kg ha^{-1}), colonial bent grass (*Agrostis vulgaris* With.syn. *Agrostis tenuis* Sibth. and *Agrostis capillaris* L.) of the 'Frasek' cultivar (34 kg ha^{-1}), and the annual dwarf nasturtium (*Tropaeolum majus nanum* L.) 'Empress of India' (26 kg ha^{-1}). The perennial cover crop – blue fescue (*Festuca ovina*) of the 'Edolana' cultivar, was sown in spring 2005 (30 kg ha^{-1}) to replace annual dwarf nasturtium, because of insufficient percentage of the soil surface cover under nasturtium plants.

The experiment was established with modified two-factor split-plot design. The main-plot factor was orchard floor management system represented by three living mulches. The living mulches were sown in the tree rows, with four replications. The second factor – rootstock (trees grafted on three different rootstocks) – supplied the subplot level. Within each replication – within living mulch main plot (18 × 1 m), three subplots (6 × 1 m) with the five trees on three different rootstocks were delimited. Each main plot contained five trees grafted on P 22 and five trees on P 16, as well as five trees on P 2 rootstock. The experiment consisted of 12 main plots, containing 36 subplots.

Manual weed suppression was performed within living mulches: colonial bent grass and dwarf nasturtium plants in the year of their sowing (2004). In the same year, only the overgrown weeds within a dense sod of the white clover, that grew above the level of the living mulch plants, were cut manually. After the year of the annual dwarf nasturtium cultivation (2004), prior to sowing of the blue fescue

(2005), chemical weed suppression involving a mix of glyphosate and 2-methyl-4-chlorophenoxyacetic acid (MCPA) was administered at a dosage of 2,880 g ha^{-1} and 750 g ha^{-1}, respectively. In the year of blue fescue sowing (2005), manual weed suppression was performed within grass, as done after germination of the colonial bent grass. In the second year following blue fescue sowing (2006), dicotyledonous weeds developing within the grass sod were treated with an herbicide based on MCPA, applied at a dosage of 1,000 g ha^{-1}. The separate herbicide application enabled better living mulch growth, which complemented blue fescue sod development, resulting from delayed sowing in comparison with colonial bent grass and white clover.

All the living mulches in the tree rows were mowed manually, most frequently twice a vegetation season, since the third year of their sowing. Between the tree rows, a mix of permanent grass sod was introduced in the first year after the planting of the trees. It was mown mechanically several times per vegetation season. The trees were trained into the form of a slender spindle. Fertilization and protection of the apple trees were carried out in accordance with the recommendations of current agrotechnical methods.

The weed species occurring in the living mulches have been assessed since the year of the orchard establishment (2004) up to the thirteenth year after planting of the trees (2016). The degree of soil coverage by living mulches was assessed as the percentage of the total subplot surface (6 × 1 m) occupied by the mulching plants, with a 5% measurement error. Using the same plots, the percentage of the soil surface occupied by separate weed species was determined. For this purpose, a noninvasive method of weed population assessment, conforming to the methodology of Lipecki and Janisz (2000), was employed. The assessments were performed separately for each weed species, in some cases – genus. The proportion of the plot area occupied by each species was expressed using a discrete percentage scale: 0%, 20%, 40%, 60%, 80%, and 100%. As the share of each species was assessed independently, it was impossible to express the relationship between the total share of all weed populations and the sod of the living mulch at a scale of 100%. The first assessment of weed occurrence and cover crop sods took place in the year of the living mulch sowing (2004), after the emergence of the cover crops. In the subsequent years (2005–2016), the evaluation was done in July. The nomenclature of vascular plants was based on Erhardt et al. (2008).

The present study shows the final findings of the abundance of the most important annual and perennial weed species occurring in the three living mulch treatments during 13 years of the orchard training. The data obtained in the young orchard (2004–2006) and every second year, starting from the year 2008, pertaining to the degree of soil coverage by living mulch plants and the most important weeds, were analyzed using one-way analysis of variance. Although the experiment was established with a modified two-factor split-plot design, the statistical assessment was focused on the main-plot factor – living mulches, which enabled us to use a one-way analysis of variance for a randomized block design. The statistical analysis took into account main-plots data for each living mulch, which was obtained as a mean of three subplots data (for the subplots with trees on three different rootstocks). The value related to the abundance of weeds included at least 5% coverage of plot area by each separate weed. The statistical evaluation was omitted when only two mean data was collected. Prior to the analysis, the data were angularly transformed (by the Bliss function). Multiple comparisons were performed at the 5% significance level using Duncan's multiple range test.

3. Results

The annual precipitation in the orchard was uneven during the first 13 years of the living mulches maintenance (Table 1). The January–June precipitation sums registered in the young orchard were similar across the first 3 years after planting of the trees. The monthly precipitation distributions were variable, with particularly large differences occurring for May and June – the months corresponding to the

most intensive growth of both weeds and living mulches. Among the following years, 2009 turned out to be particularly wet, with the precipitation sum exceeding 400 mm in the first 6 months, while 2015 was very dry.

A relationship was observed between the counts of identified weed taxa and the dominances of each of the investigated cover crops (Table 2, Table 3). The high weed species diversity, initially observed in the year of living mulch sowing, significantly reduced in the years of increasing living mulch covers. White clover dominated only in the first 3 years of the orchard maintenance. The grass mulches turned out to be superior and the presence of colonial bent grass and blue fescue exceeded 80% of the soil surface area until as late as the seventh and ninth year following the orchard establishment. In subsequent years, reduction across all the investigated cover crop sods contributed to the reemergence of the weed taxa number.

Annual weeds prevailed over perennial species in the year of cover crop sowing (Table 4, Table 5). *Chenopodium album* L. was the most important weed species in the white clover sod. Still, the decrease of this living mulch sod, observed already in 2008, was related to the spreading of a perennial weed *Elymus repens* (L.) Gould. This species was already present in the year of the orchard establishment. With increasing occurrence of other Poaceae and some dicotyledonous species, the sod of white clover became permanently suppressed. Perennial weeds and reemerged annual *Stellaria media* (L.) Vill. were the main species noted in the tree rows with white clover, 13 years after the orchard planting.

The infestation of annual weeds became marginal in the second and third year of the grass living mulch maintenance. On the other hand, *Elymus repens* and *Taraxacum officinale* Web. were abundant at that time (Table 4, Table 5). Colonial bent grass

Table 1 Total precipitations (mm) during the first 6 months at the Fruit Experimental Station in Samotwór (51°06′12″ N, 16°49′52″ E) in the years 2004–2016.

Year after tree planting	Year	Month						Total	Total
		I	II	III	IV	V	VI	I–VI	V–VI
1st – orchard establishment	2004	47.4	40.4	63.4	21.7	33.1	38.7	244.7	71.8
2nd	2005	25.9	44.8	2.9	26.2	122.8	28.8	251.4	151.6
3rd	2006	55.0	33.4	24.9	48.6	16.3	69.1	247.3	85.4
4th	2007	45.8	41.2	48.6	8.2	52.3	104.2	300.3	156.5
5th	2008	57.7	15.0	36.5	74.5	50.5	32.9	267.1	83.4
6th	2009	35.0	67.0	43.8	11.5	87.8	165.9	411.0	253.7
7th	2010	26.0	8.5	32.4	33.2	107.5	34.0	241.6	141.5
8th	2011	22.0	6.5	32.0	26.7	66.0	49.3	202.5	115.3
9h	2012	45.6	32.6	11.8	25.4	26.2	79.4	221.0	105.6
10th	2013	33.0	20.8	24.6	35.3	97.6	98.0	309.3	195.6
11th	2014	24.8	2.6	30.8	27.8	103.6	25.4	215.0	129.0
12th	2015	34.6	5.3	15.7	11,7	25.0	59.2	151.5	84.2
13th	2016	26.4	35.6	50.4	41.0	33.0	64.2	250.6	97.2

Table 2 Change in the mean percentage of the soil surface under the three living mulch sod cover in the tree rows, in the succeeding years 2004–2016.

Living mulch species	Period and year after trees planting							
	Orchard establishment	Young orchard		Full cropping orchard				
	1st (2004)	2nd (2005)	3rd (2006)	5th (2008)	7th (2010)	9th (2012)	11th (2014)	13th (2016)
White clover	20.0	100.0 b	95.0	5.4 a	41.7 a	5.4 a	4.6 a	5.0 a
Colonial bent grass	43.3	100.0 b	99.2	95.4 b	81.7 b	33.8 b	45.8 b	40.8 b
Blue fescue*	21.7	13.8 a	93.3	100.0 b	97.9 b	81.3 c	44.2 b	41.7 b

* In 2004 dwarf nasturtium living mulch.
Within individual columns, the means marked with varied letters differ significantly according to the Duncan's test at the confidence level 95%.

Table 3 Number of the identified weed taxa on the soil surface in the tree rows with the living mulch sod, in the succeeding years 2004–2016.

Living mulch species	Period and year after trees planting							
	Orchard establishment	Young orchard		Full cropping orchard				
	1st (2004)	2nd (2005)	3rd (2006)	5th (2008)	7th (2010)	9th (2012)	11th (2014)	13th (2016)
White clover	36	23	15	21	14	24	23	19
Colonial bent grass	36	21	14	21	22	24	22	29
Blue fescue*	34	30	24	13	10	21	20	24

* In 2004 dwarf nasturtium living mulch.

diminished to a large extent relative to blue fescue by the time the trees reached the age of 10 years. This was due to the suppression by *Elymus repens*, rapidly spreading in the former mulch. Starting from the eleventh year following the apple trees planting, the dominances of the individual living mulches were similar, and remained below 50% until the end of the study. Increased populations of some perennial weeds contributed to the suppression of living mulch sods.

Among the most important perennial weeds, a notable variation in the *Elymus repens* occurrence can be discerned for the three examined living mulches (Table 6). A significant dominance gain by this species was noted in white clover compared to blue fescue and, in some years, to colonial bent grass, as well. The presence of the remaining perennial dicotyledonous weeds was even, with only sporadic increases of *Achillea millefolium* L. in colonial bent grass and white clover. *Taraxacum officinale* in blue fescue clearly increased more than twice relative to other living mulches in the year 2006.

4. Discussion

The composition of flora in orchards is modified by environmental conditions, succession, and the age of the orchard (Lisek, 2012). Highly abundant populations of several annual weed species occurred in the tree rows in the year of the orchard establishment, when white clover and colonial bent grass were sown. The significance of these weeds diminished within the second year of the experiment. The space, which is essential for annual weed functioning (Wallinga et al., 2002; Wang et al., 2003), became thoroughly occupied by the living mulch sod. Since such conditions do not favor seed germination (Bond & Grundy, 2001), the occurrence of annuals in the orchard became marginal. Similar tendencies were observed in the blue fescue, which had been sown in the second year following the apple tree planting.

The living mulch persistence in later years varied depending on its infestation with perennial weeds. White clover spread to a satisfactory degree across the space within the apple tree rows, within the second year of the cover crop maintenance. Its occurrence precluded the dominance and increase of perennial weeds present in the orchard since the year of the living mulch sowing. This pattern agrees with the results of Ross et al. (2001), who compared weed suppression capabilities of seven clover species maintained over 2 years. They obtained weed dry mass reduction despite relatively small white clover biomass. Adequate suppression of weeds present in white clover sod was corroborated also by den Hollander et al. (2007b), based on research of similar short duration.

Nevertheless, substantial reduction of white clover sod was noted in the subsequent years of the present study. An alarming increase of *Elymus repens* dominance was observed as early as in the third year of the experiment. This monocotyledonous weed can infest living mulches within the time of orchard maturation (Lipecki & Janisz, 2001). Its prevalence in the investigated orchard persisted throughout the research years, leading to a drastic reduction in living mulch dominance. Elevated occurrence of perennial dicotyledonous weeds and various grasses, or

Table 4 Change in the mean percentage of the soil surface under the most important annual weed cover in the tree rows with the living mulch sod, in the succeeding years 2004–2016.

Period and year after trees planting		Weed species*							
		C.b-p.	C.h.	C.	C.a.	E.c-g.	P.a.	S.v.	S.m.
White clover									
Orchard establishment	1st (2004)	40	–	40	80	40	20	20	40
Young orchard	2nd (2005)	–	–	20	20	20	20	–	20
	3rd (2006)	20	–	20	20	–	20	20	–
Full cropping orchard	5th (2008)	–	–	–	20	–	20	20	20
	7th (2010)	–	–	–	20	–	–	–	20
	9th (2012)	20	20	20	20	–	20	20	20
	11th (2014)	20	20	–	20	–	20	20	20
	13th (2016)	–	–	20	20	–	20	–	80
Colonial bent grass									
Orchard establishment	1st (2004)	40	–	60	60	60	40	20	60
Young orchard	2nd (2005)	–	–	20	–	–	–	–	20
	3rd (2006)	20	–	–	–	–	–	–	–
Full cropping orchard	5th (2008)	20	–	20	20	–	20	20	20
	7th (2010)	–	–	20	–	–	20	20	20
	9th (2012)	20	20	20	20	–	20	–	20
	11th (2014)	–	20	–	–	–	–	–	20
	13th (2016)	20	40	20	20	–	20	–	40
Blue fescue**									
Orchard establishment	1st (2004)	20	–	60	80	40	40	40	80
Young orchard	2nd (2005)	40	–	40	40	100	20	60	20
	3rd (2006)	20	–	20	20	20	–	20	20
Full cropping orchard	5th (2008)	–	–	–	–	–	–	–	20
	7th (2010)	20	–	20	–	–	–	20	–
	9th (2012)	20	20	20	20	–	–	–	20
	11th (2014)	20	20	–	20	–	–	20	20
	13th (2016)	–	40	20	20	–	20	20	60

* C.b-p. – *Capsella bursa-pastoris* (L.) Med.; C.h. – *Cerastium holosteoides* Fr. em Hyl.; C. – *Chamomilla* spp.; C.a. – *Chenopodium album* L.; E.c-g. – *Echinochloa crus-galli* (L.) P. B.; P.a. – *Polygonum aviculare* L.; S.v. – *Senecio vulgaris* L.; S.m. – *Stellaria media* (L.) Vill.

** In 2004 dwarf nasturtium living mulch.

Species occurring: 20 – in small numbers up to the 20% of the soil surface; 40 – between the 21%–40% of the soil surface; 60 – between the 41%–60% of the soil surface; 80 – numerously between the 61%–80% of the soil surface; 100 – dominantly over the 80% up to the 100% of the soil surface; "–" – lack of the species.

even secondary infestation by annuals, mainly *Stellaria media*, was noted under 13-year-old tree canopies in addition to the discussed species. Similarly, white clover maintained in tree rows exhibited higher weed infestation relative to other living mulches studied by Hogue et al. (2010) over a short period of 6 years. Conversely, total weed infestation of white clover was low in an older orchard investigated by Granatstein and Mullinix (2008).

The occurrence of perennial weeds by the year of the living mulch sowing points to the insufficient weed control exercised on the soil prior to the planting of trees for the present experiment. White clover, a species from the Fabaceae family, thus valued for the atmospheric nitrogen fixation (den Hollander et al., 2007a), did not perform satisfactorily as a living mulch in the orchard. It is also worth mentioning that, as reported by Licznar-Małańczuk (2012), both its sod and the weeds coexisting within, impaired the growth and yield of the young trees by the fifth year of the experiment. In contrast, the living mulches from the Poaceae family were less prone to becoming weed-infested and exhibited higher permanence. In addition, blue fescue was the least competitive towards apple trees.

Table 5 Change in the mean percentage of the soil surface under the most important perennial weed cover in the tree rows with the living mulch sod, in the succeeding years 2004–2016.

Period and year after trees planting		Weed species*							
		A.m.	C.a.	E.r.	M.s.	P.	S.a.	T.o.	T.r.
White clover									
Orchard establishment	1st (2004)	–	20	60	20	–	20	20	×
Young orchard	2nd (2005)	–	20	40	20	20	20	40	×
	3rd (2006)	–	20	80	20	20	20	40	×
Full cropping orchard	5th (2008)	20	20	100	20	20	20	20	×
	7th (2010)	20	20	100	20	40	20	20	×
	9th (2012)	20	40	100	20	40	20	40	×
	11th (2014)	20	20	100	20	60	40	20	×
	13th (2016)	40	40	80	20	40	60	40	×
Colonial bent grass									
Orchard establishment	1st (2004)	20	20	60	20	–	20	40	20
Young orchard	2nd (2005)	20	20	80	20	–	20	40	20
	3rd (2006)	20	20	60	20	–	20	40	20
Full cropping orchard	5th (2008)	20	20	80	20	20	20	20	20
	7th (2010)	20	20	100	–	20	20	20	20
	9th (2012)	20	40	100	20	–	20	40	20
	11th (2014)	40	40	80	20	20	20	20	40
	13th (2016)	40	40	60	20	60	40	40	20
Blue fescue**									
Orchard establishment	1st (2004)	–	20	80	20	–	20	40	20
Young orchard	2nd (2005)	–	20	20	20	20	20	40	20
	3rd (2006)	20	20	40	20	20	20	60	40
Full cropping orchard	5th (2008)	20	20	40	20	–	20	20	20
	7th (2010)	–	20	40	–	–	–	20	20
	9th (2012)	20	40	60	–	20	20	20	20
	11th (2014)	20	40	80	20	–	20	20	20
	13th (2016)	20	60	60	20	20	40	40	20

* A.m. – *Achillea millefolium* L.; C.a. – *Convolvulus arvensis* L.; E.r. – *Elymus repens* (L.) Gould; M.s. – *Malva sylvestris* L.; P. – Poaceae – different species; S.a. – *Sonchus arvensis* L.; T.o. – *Taraxacum officinale* Web.; T.r. – *Trifolium repens* L.

** In 2004 dwarf nasturtium living mulch.

Species occurring: 20 – in small numbers up to the 20% of the soil surface; 40 – between the 21%–40% of the soil surface; 60 – between the 41%–60% of the soil surface; 80 – numerously between the 61%–80% of the soil surface; 100 – dominantly over the 80% up to the 100% of the soil surface; "–" – lack of the species; × – without evaluation.

The high, yet stable *Elymus repens* infestation during the first few years of colonial bent grass maintenance probably stemmed from the satisfactory living mulch coverage. *Taraxacum officinale*, a dicotyledonous weed species commonly found in grass mulches (Tworkoski & Glenn, 2012), was less abundant. Another observation was the enormous increase in the population of *Elymus repens*, starting from the fifth year following the planting of trees. Although its prevalence continued through the thirteenth year of the orchard existence, the dominance of Poaceae and dicotyledonous species, *Achillea millefolium* and *Convolvulus arvensis* L., was also significant. The specific composition of the tree rows began to resemble the vegetation of an orchard whose floor had never been managed by herbicides or maintained with cover crops (Tebeau et al., 2017).

Elymus repens exhibited limited dominance in the sod of blue fescue in the period between its sowing and the seventh year of its maintenance. This was likely due to a more thorough soil preparation, which had been accomplished by hand weeding of the first living mulch – dwarf nasturtium – 1 year prior to the blue fescue introduction. The single herbicide application in the second year of blue

Table 6 Differences between three living mulch sods in the mean percentage of soil surface under the most important perennial weed cover in the tree rows, in the succeeding years 2004–2016.

Living mulch species	Period and year after trees planting							
	Orchard establishment	Young orchard		Full cropping orchard				
	1st (2004)	2nd (2005)	3rd (2006)	5th (2008)	7th (2010)	9th (2012)	11th (2014)	13th (2016)
Achillea millefolium L.								
White clover	–	–	–	5.0	6.7	8.3	10.0 ab	28.3
Colonial bent grass	10.0	11.7	15.0	16.7	16.7	18.3	26.7 b	36.7
Blue fescue*	–	–	–	–	–	–	5.0 a	10.0
Convolvulus arvensis L.								
White clover	10.0	10.0	15.0	15.0	15.0	21.7	18.3	30.0
Colonial bent grass	15.0	16.7	18.3	18.3	16.7	26.7	31.7	38.3
Blue fescue*	15.0	20.0	10.0	15.0	16.7	26.7	33.3	41.7
Elymus repens (L.) Gould								
White clover	41.7	35.0 b	78.3 c	95.0 c	91.7 b	91.7 b	98.3	78.3 b
Colonial bent grass	60.0	65.0 c	50.0 b	73.3 b	86.7 b	95.0 b	80.0	50.0 a
Blue fescue*	63.3	13.3 a	21.7 a	23.3 a	23.3 a	53.3 a	75.0	51.7 a
Malva sylvestris L.								
White clover	6.7	8.3	–	5.0	5.0	–	8.3	11.7
Colonial bent grass	–	5.0	–	5.0	–	–	5.0	–
Blue fescue*	10.0	13.3	16.7	5.0	–	–	–	–
Poaceae different species								
White clover	–	20.0	16.7	11.7	31.7	21.7	48.3	40.0 b
Colonial bent grass	–	–	–	10.0	18.3	–	–	43.3 b
Blue fescue*	–	–	11.7	–	–	–	–	10.0 a
Sonchus arvensis L.								
White clover	–	–	–	6.7	8.3	13.3	23.3	50.0
Colonial bent grass	–	6.7	–	–	–	10.0	10.0	21.7
Blue fescue*	–	5.0	–	6.7	–	8.3	16.7	21.7
Taraxacum officinale Web.								
White clover	20.0	23.3	21.7 a	20.0	18.3	33.3	18.3	25.0
Colonial bent grass	21.7	35.0	25.0 a	18.3	16.7	21.7	11.7	21.7
Blue fescue*	21.7	25.0	53.3 b	–	8.3	20.0	8.3	21.7
Trifolium repens L.								
White clover	×	×	×	×	×	×	×	×
Colonial bent grass	11.7	15.0	11.7	15.0	16.7	16.7	21.7	11.7
Blue fescue*	–	10.0	21.7	18.3	20.0	6.7	20.0	13.3

* In 2004 dwarf nasturtium living mulch.
"–" – weed occurrence lower than 5%, without statistical evaluation; × – without evaluation.
Within individual columns, the means marked with varied letters differ significantly according to the Duncan's test at the confidence level 95%.

fescue maintenance additionally contributed to the suppression of the living mulch weed infestation. A similar intervention fostered living mulch soil coverage in the study by Hartley et al. (2000). The weed occurrence in both grasses might have been also modified by mowing of the sod in the later years. A combination of the grass and an annual mowing increased weed suppression in time (Tworkoski & Glenn, 2012) and decreased weed species richness in the orchard (Tursun et al., 2018). These operations did not preclude, however, the dominances of the blue fescue and colonial bent grass from reducing by the end of the study to below the level of half of the tree row surface area. Perhaps, an herbicide reapplication in a few-year-old orchard would have shielded the blue fescue sod against the dicotyledonous weed dominance increase. Per se, chemical weed control might have had a positive influence on colonial bent grass. Resowing (Hartley et al., 2000) or sowing rate

increase (Tworkoski & Glenn, 2012) are other notable methods that can strengthen a living mulch. Nevertheless, the occurrence of *Elymus repens* populations, present already in the year of living mulches sowing, turned out to be the biggest problem, rather than the choice of proper management and agritechnical methods. Although grasses can limit the rhizomatous spreading of this weed, their effectiveness varies across the species (Marshall, 1990). On the other hand, proper agritechnical interventions can foster certain grasses to suppress the weed occurrence in their vicinity.

5. Conclusions

Although long-term maintenance of living mulches in an orchard suppresses annual weed occurrence to a marginal level, it is not an effective agritechnical method to prevent the spreading of perennial-weed infestation in apple tree rows.

The dominance of perennial weeds, primarily *Elymus repens*, present already in the living mulch sowing year, varies dynamically in the subsequent years of orchard maintenance, and an increased population of the weeds impairs the durability and extent of the cover crops.

Meticulous soil weeding prior to the sowing of grass cover crops, combined with their delayed introduction in an orchard as well as chemical dicotyledonous weed suppression, prolongs the period of satisfactory dominance of living mulches in apple tree rows.

White clover exhibited insufficient permanence as a living mulch. Blue fescue maintained satisfactory sod dominance relative to colonial bent grass for nearly the entire first decade of the research. Although the differences in the years of sowing and the agritechnical method of cultivation of both plants did not enable comparison of these grass living mulches, as well as recommend either of them as more useful for orchard weed management.

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